REMOTE NEAR-INFRARED FUEL MONITORING SYSTEM

INTERIM REPORT
TFLRF No. XXX

By

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EXECUTIVE SUMMARY

Objective: The objectives of this study were (1) to demonstrate the feasibility of replacing standard field methods for fuel analysis with a rapid analytical technique based on near-infrared spectroscopy, (2) to design a system that could provide real-time monitoring of fuel being distributed from a bulk fuel farm, and (3) to provide the United States Marine Corps (USMC) with a system for tracking fuel inventory.

Accomplishments: Based on the requirements set forth by the United States Marine Corps, a system was designed and prototyped to monitor fuel in real-time as it was being dispensed from a remotely located bulk fuel farm. The *Remote Near-Infrared Fuel Monitor* was able to determine the quality of both diesel fuel and kerosene and relay this information back to a remote monitoring station. The system also allowed the entry of fuel inventory data for the purpose of tracking fuel usage and fuel on hand.

Military Impact: The advantages of using the Remote Near-Infrared Fuel Monitor are overwhelming. When placed in-line in a bulk fuel farm, distribution of contaminated fuel could be virtually eliminated. This small effort could (1) limit the number of maintenance personnel and spare parts (*e.g.* fuel filters) that must be maintained on the battlefield, (2) reduce the frequency of fuel related vehicle problems, and (3) increase combat readiness. Fuel being delivered to the farm may also be tested prior to receipt. This could prevent a contaminated shipment from contaminating the rest of the fuel supply. Also, captured fuels may be tested and identified *on the battlefield* prior to use, eliminating the time consuming task of transporting a sample to the rear for evaluation. In addition, tracking fuel inventory electronically, and in real-time, allows the rear command to anticipate future fuel requirements. Using the Remote Near-Infrared Fuel Monitor allows a pro-active, rather than reactive, approach to fuel management.

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I. OBJECTIVE

The objectives of this study were (1) to demonstrate the feasibility of replacing standard field methods for fuel analysis with a rapid analytical technique based on near-infrared spectroscopy, (2) to design a system that could monitor fuel being received and distributed from a bulk fuel farm, and (3) to provide the United States Marine Corps (USMC) with a system for tracking fuel inventory.

II. INTRODUCTION AND BACKGROUND

Believing that a number of vehicle maintenance problems stem from poor or contaminated fuel, the United States Marine Corps sought to develop the capability to monitor fuel quality in the field in real-time. The current protocol is to test fuel only after a vehicle has been diagnosed with fuel-related problems. By using a proactive rather than reactive management of their fuel supply, the USMC postulated that it could ultimately reduce maintenance personnel and spare part requirements thus augmenting their operational readiness.

The USMC commissioned the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) at Southwest Research Institute (SwRI) to develop a system, based on a near-infrared spectrometer, that could monitor fuel quality "in-line" as it was being dispensed. Since SwRI had been investigating a similar system for the U.S. Army, most of the knowledge required to implement such a system was already in hand (1, 2). The system being investigated for the Army had to undergo only a few minor modifications to allow it to acquire information on flowing fuel in real-time. To expedite the completion of the USMC system, the U. S. Army agreed to transfer one of its existing near-infrared instruments to the USMC. Upon completion, the Remote Fuel Monitor was to be deployed in Twenty-nine Palms, CA during Hunter-Warrior in early 1997.

III. TECHNICAL APPROACH

SwRI had a near-infrared spectrometer ruggedized to withstand the desert environment in which it would be deployed for the Hunter-Warrior exercise. A pipe section was constructed to contain the sensor package (fiber-optic probe, flowmeter, thermocouple). The pipe section was outfitted with quick disconnects so that it could be easily inserted into the USMC's current fuel distribution system. Two computers were acquired for controlling and monitoring the instrument: a ruggedized laptop for primary control of the system and a desktop PC to be used as a remote monitoring station. A siren and an alarm were built into the system to warn operators of out-of-tolerance fuel.

Customized software was designed for both the laptop and the desktop PC. Each version of the software had the ability to display historical fuel inventory data. In addition, the software for the laptop computer contained the primary interface for the instruments functions and the calculations for generating the fuel property estimates. The fuel property calibrations required for the near-infrared spectrometer had already been generated under the Army's project.

For testing purposes, the Remote Fuel Monitor was deployed in a bulk-fuel farm in Twenty-nine Palms, CA during Hunter-Warrior in 1997. The desktop PC was located at the CSSOC at Camp Pendleton. The system was subjected to a battery of tests involving both acceptable and contaminated fuels. Experiments were conducted using diesel, JP-5, and MOGAS.

The following criteria were used to judge the success of the Remote Fuel Monitor:

1. The system must be able to detect changes in the property estimates when substances other than diesel are sent through the system.
2. The system should issue an alarm when out-of-tolerance properties are detected so that operators can stop distributing fuel.

3. At the CSSOC, the system should indicate which properties are out-of-tolerance so that corrective action can be taken.

IV. THEORY OF OPERATION

A. NEAR-INFRARED SPECTROSCOPY

The most utilized portion of the near-infrared region is that between 1000 and 2500 nm (10,000 - 4,000 cm^{-1}). For organic molecules, near-infrared spectra are the result of combination and overtone bands of the fundamental vibrational frequencies found in the mid-infrared region (3). Overtone bands appear at integer multiples (approximately) of the fundamental vibrational frequencies and each subsequent overtone is dramatically weaker in intensity. The first overtone for a fundamental vibrational frequency in the mid-infrared region appears at twice the wavenumber (or one half of the wavelength), the second overtone appears at three times the wavenumber (or one third of the wavelength), *etc.* For this reason, near-infrared spectra are typically comprised of first and second overtones of C-H, N-H, and O-H stretching vibrations. Other vibrational modes (*e.g.* bending, scissoring, *etc.*) and other functional groups (*e.g.* C-O-C, C=C, *etc.*) can contribute to the spectrum through combination bands. This makes near-infrared spectroscopy highly suitable for use with hydrocarbon fuels. However, to be useful a correlation must exist between the minor spectral differences related to fuel composition and the fuel property of interest.

Near-infrared light emitted from a tungsten-halogen light source is transmitted through the fuel and detected on the other side. As the light passes through the fuel, a variety of chemical species will absorb the light at various wavelengths and to varying degrees. As a result, the characteristics of the fuel will be imparted on the near-infrared spectrum. The instrument's detector measures the intensity of the transmitted light and generates an absorbance spectrum over the selected wavelength range (example shown in Figure 1). Unlike some analyzers that detect only a few wavelengths of the transmitted light, the spectrometer used in this work

performs a full spectral analysis which may contain 300 or more wavelengths. Fuel properties can be correlated to the subtle spectral changes that are present from sample to sample. These spectral changes represent the variation in the fuel properties and can be quantified.

B. CHEMOMETRICS

Chemometrics is a branch of chemistry that applies mathematical and statistical routines to chemical and physical data. The goal is to relate the state (*i.e.* a chemical or physical characteristic) of a system to measurements (*e.g.* spectral data) collected on the system. A significant factor contributing to the popularity and growth of chemometrics is that the vast amounts of spectral data being generated by today's analytical instruments is not being utilized to its full potential. This is due, in part, to the fact that much of the useful information contained in the spectra is the way in which individual measurements co-vary. The situation is complicated by the fact that the some of the information is redundant and some degree of noise is present in the spectra. Chemometric routines compress the spectra by extracting only the essential information and leaving behind most of the noise and redundancies. The result is that the changes in the spectra can be described using far fewer variables (wavelengths) without a significant loss of relevant information. Ultimately, the compressed spectral data must be correlated to the fuel property data to be useful.

In many cases, rather than measuring individual chemical components, a bulk property of the system like density is sought. The term given to this type of observation is *indirect* because the value of the bulk property is inferred from the overall chemical composition of the system (4, 5). This is entirely feasible because the chemical composition governs the value of the bulk property and is reflected in the spectral data. All that remains is to uncover the mathematical relationship between the spectral data and the property of interest. This work utilized linear calibration models generated from a Partial Least Squares (PLS) regression. These models assume that the near-infrared spectra result from linear combinations of the

individual chemical components found in fuel.

V. THE REMOTE FUEL MONITOR

A. CONFIGURATION

The prototype system (Figures 2, 3, and 4) contained the following features:

- Rack-mounted, near-infrared spectrometer (with two internal cooling fans)
- Pipe section:
  - quick disconnects to connect to the existing USMC fuel distribution system (4 inch hoses)
  - flow meter
  - thermocouple
  - sampling port
  - in-line, fiber-optic transreflectance probe
- One (1) external sampling device (probe)
- Ruggedized laptop computer - provided primary control for the instrument
- Desktop computer (Remote Fuel Monitoring Workstation)
- Custom software for instrument control and inventory tracking
- Real-time acquisition of fuel-quality data
- Flow-activated scanning
- Warning light and alarm
- Real-time transmission of fuel inventory/quality data from the laptop to the desktop via TCP/IP

The Remote Near-Infrared Fuel Monitor was based on a near-infrared process analyzer that was ruggedized for field use. Fiber-optic cables coupled to a fiber-optic probe were used to collect near-infrared spectra of the flowing fuel as it was being dispensed. A pipe section

was developed that could be quickly inserted into the USMC's current fuel distribution system. The fiber-optic probe, flow meter, sampling port, and thermocouple were installed in the pipe section. The Remote Fuel Monitor utilized a ruggedized laptop (fieldworks, Inc.) to control all of the spectrometer's functions, allow for entry of fuel inventory data, and transmit the fuel inventory and quality data over TCP/IP to a remotely located workstation. The fuel quality and inventory data was stored in a database on the laptop and on the remote workstation. Each computer had the ability to show the current status of the fuel supply and to view historical data.

B. INSTRUMENT CALIBRATION

The fuel property calibrations for the near-infrared spectrometer were generated using a database of approximately 800 fuel samples. Although the fuel samples were primarily diesel (about 5% of the set were aviation kerosenes), the calibrations were also applicable to kerosene samples because they share many of the same characteristics. The sample set was split into two equal groups to create a calibration training set and a validation set. Using the calibration training set, Partial Least Squares (PLS) calibration models were developed for each of the following fuel properties: Density (ASTM D4052), g/mL at 15°C; Viscosity (ASTM D445), cSt at 40°C; Total Aromatic Content (ASTM D 5186), mass%; Cetane Index (D 4737); Net Heat of Combustion (ASTM D 240), MJ/Kg; Cloud Point (ASTM D 2500), °C. While calibration models for over 30 fuel properties are available, their degrees of accuracy vary. These properties were chosen because they provide the most accurate estimates and the most information concerning the quality of the fuel. The validation set was used to test the calibration models once they were created.

Table 1 summarizes the calibration results and indicates the range over which the fuel properties were calibrated; while the model can estimate fuel property values outside of this range, the estimation would be an extrapolation of the model and more susceptible to deviation from the true value. The Standard Error of Prediction (SEP) is an estimate of the

Table 1. Calibration Summary

Property	Range	SEP
Density, g/mL @ 15°C	0.7883 - 0.8728	0.0028
Viscosity, cSt @ 40°C	1.20 - 3.92	0.18
Total Aromatic Content, mass%	10.7 - 47.2	1.1
Cetane Index	40.2 - 60.1	0.98
Net Heat of Combustion, MJ/Kg	42.29 - 43.46	0.06
Cloud Point, °C	(-60.5) - (-2.6)	4.6

average error in the calibration and was generated according to Equation 1,

$$SEP = \frac{\sqrt{\sum (estimated - actual)^2}}{n}$$

where *n* is the number of samples, *estimated* is the near-infrared estimated value, and *actual* is the reference value determined by the standard ASTM method.

Figures 5-10 show Predicted *vs.* Actual plots for the validation tests plotted against a perfect fit line. One distinguishing feature is that of the two distinct clusters seen in Figure 10 for cloud point; the top cluster represents the diesel samples and the lower cluster represents the kerosenes. Ultimately, separate calibrations for each fuel type should provide the best results. Some of the plots show stray samples that deviate considerably. It is inevitable that some samples may not be estimated properly. This may occur if the fuel is unique in some way (*e.g.* contains contaminants or additives that were not present in any of the calibration samples). The proper method for handling such samples is to have them thoroughly analyzed by the standard methods and then, if appropriate, added to the near-infrared calibrations. The ultimate goal is to make the sample database representative of the types of samples that are expected to be analyzed in the future.

C. MODE OF OPERATION

Triggered by flow in the line, the system collects a near-infrared spectrum of the fuel every ten seconds while flow is detected. If the fuel is determined to be out of tolerance, the alarm sounds allowing attendants to halt fueling before a significant amount of fuel reaches the vehicle. In addition, the system automatically collects a spectrum when 30 minutes elapse without detection of flow. By also incorporating an external sampling device (probe), additional samples like fuel shipments and fuel extracted from vehicles, can be analyzed. As a result, contaminated fuel will not be received or dispensed.

With the ability to track fuel inventory, an attendant can quickly determine the total volume of fuel dispensed and fuel on hand. The volume of fuel dispensed to individual units or over a given period of time can also be charted. The fuel inventory/quality data that is collected can be transmitted in real-time via TCP/IP to a workstation in the rear. This allows the rear command to be immediately aware of possible fuel-related problems and to anticipate the fuel farm's future fuel requirements.

The overall fuel quality is determined by comparing the estimated property values to predefined limits. The limits rate each estimated value as good (green), acceptable (yellow), or fail (red), and are depicted as colored 'meatballs' in the software. The overall fuel quality is defined as the lowest rating received by any of the properties, *i.e.*, if five properties were "good" and one was "fail," the overall rating would be "fail." An overall rating of "fail" would cause the alarm to sound. Table 2 shows the fuel property limits used during Hunter-Warrior.

D. SOFTWARE

The custom software for the laptop and the desktop PC was written in Microsoft® Visual Basic® 4.0. The TCP/IP capability was developed using PowerTCP™ (Dart Communications), an ActiveX control for Visual Basic®.

Table 2. Fuel Property Limits

Property	Fail	Acceptable	Good	Acceptable	Fail
Density, g/mL @ 15°C	<0.77	<0.80	0.80 to 0.86	>0.86	>0.91
Viscosity, cSt @ 40°C	<0.9	<1.3	1.3 to 3.9	>3.9	>4.5
Total Aromatics, mass%	<5	<10	10 to 50	>50	>60
Cetane Index	<35	<40	40 to 55	>55	>60
Net Ht Comb, MJ/Kg	<41	<42	42 to 43	>43	>45
Cloud Point, °C	<-75	<-10	-10 to -1	>-1	>2.1

1. INSTRUMENT CONTROL SOFTWARE

Figure 11 shows a screenshot of the instrument control software taken during the development phase. This software resided on the laptop and provided the primary interface to the instruments functions and the point at which fuel inventory data was entered. The grid displays the fuel quality data indicating the status of each property and the overall status of the fuel. The amount of fuel on hand, fuel received, and fuel dispensed is also displayed and the means are provided for graphing and sorting the fuel inventory data by date and unit.

2. INVENTORY CONTROL SOFTWARE

Figure 12 shows a screenshot of the inventory control software taken during the development phase. This software resided on the desktop PC and was used to monitor the status of the fuel at the remotely located bulk fuel farm. The desktop PC received its information from the laptop via TCP/IP. This software provided similar functionality to the laptop's software for displaying fuel quality and inventory data. However, this software lacked the ability to control the instrument.

VI. EXPERIMENTAL

The fuels were scanned over the wavelength range of 1000-1600 nm in 2 nm increments resulting in a spectrum of 301 data points. Each near-infrared fuel spectrum was collected

as an average of 32 complete scans with a total scan time of approximately 5 seconds. The spectra were mathematically pre-treated by generating first-difference spectra followed by mean-centering. Calculating first-difference spectra involves subtraction of adjacent data points. For a spectrum, **x**, with *n* points the first-difference spectrum would be: $[(\mathbf{x}_2-\mathbf{x}_1), (\mathbf{x}_3-\mathbf{x}_2), ...(\mathbf{x}_n-\mathbf{x}_{n-1})]$. Mean-centering is accomplished by subtracting the average spectrum of all the spectra from each individual spectrum. First-difference preprocessing removes any baseline offset in the spectra. Mean-centering enhances the minor spectral differences related to fuel composition by removing a major component of useless spectral variation, the non-zero mean.

Because the experimentation was carried out on a fuel distribution system that was in use at the time, the majority of the fuel testing was conducted through the use of the external probe. Experiments were conducted using diesel, JP-5, and MOGAS. Tests were conducted by mixing various fuel types to see how the system would respond. Although the prototype system was designed primarily for diesel, a requirement of the system was that it be able to indicate when a substance other than diesel was present. Because JP-5 and diesel are almost indistinguishable by near-infrared, we expected that the system would respond similarly to each.

VII. RESULTS AND DISCUSSION

For the required criteria (*vide supra*), Items 2 and 3 were part of the original design specification and were handled effectively. An audible alarm and warning light were used to warn operators when an out-of-tolerance fuel was encountered. In addition, a warning screen and audible alarm was flashed across the laptop and the desktop PC prohibiting further use of the system until acknowledged. For item 3, on both the laptop and desktop PC, the software showed the overall fuel-quality rating as well as the individual rating for each property.

During testing, a 25% / 75% MOGAS/diesel mixture lowered the overall fuel rating to "acceptable." A 65% / 35% MOGAS/Diesel mixture was required to give a "fail" rating. As little as 1% water in diesel generated an out-of-tolerance warning. Mixtures of JP-5 and diesel were also run with all results returning a "good" rating.

Table 3 shows data that is representative of that which was generated during Hunter-Warrior. Table IV reports the ASTM reference values for the corresponding samples in Table III. Problems were discovered with the calculations for Total Aromatics and Cloud Point; every sample gave approximately the same property value. Upon inspection, errors were discovered in the calibration data and the problem was fixed when the system was returned to SwRI after Hunter-Warrior. The estimates for JP-5 were found to be only slightly worse than those for the low sulfur diesel. This was expected since the system was calibrated primarily for diesel fuel.

A. SUCCESS STORIES

The following quotes were excerpted from the USMC's after-action report for Hunter-Warrior.

> **The Fuel Monitor reported a red reading at 18:49:15 on 22 FEB. The 20,000 gallon pod had approximately 500 gallons of diesel. It is the opinion of the Fuel Farm Chief that bad fuel was indeed flowing through the system, as the bottom of the pod generally has fuel emulsified with water and dirt that has fallen into the sump. Red readings continued to occur. The decision was made to shut down the fuel farm until another fuel delivery arrived.** ***-USMC Project Officer***

> **Several samples were defueled from vehicles. The three sample sources were (1) Light Armored Vehicle (LAV), (1) High Mobility Multi-**

Wheeled Vehicle (HMMWV), and (1) 5-ton truck. The HMMWV and 5 Ton fuel samples were within tolerance (both yellow)...The LAV fuel sample scanned as out of tolerance by the external probe, a diagnosis supported by Laboratory analysis of water and particulate contamination. It was in the shop for non-fuel related problems. *-USMC Project Officer*

The Remote Fuel Monitoring system is ready to deploy now. It needs to be expanded to include all relevant fuel types: JP-5, JP-8, JA-1, etc. This system could be fielded now, both as a remote and portable capability, and realize immediate cost savings in reducing fuel related maintenance problems. This capability, once fielded, should be resident in any CSS unit responsible for providing bulk Class III support: MWSSs, ESBs, task organized CSSEs at all levels. For purposes of T/E accountability, this equipment would be resident in the MWSS, ESB, and any standing CSSE (CSSG-1, CSSG-3, etc.), as well [as] Ft. Lee for training. *-CSS Enterprise Deputy Commander's Comments on Remote Fuel Monitoring*

VIII. SUGGESTED MODIFICATIONS

The following is a list of potential upgrades to the Remote Near-Infrared Fuel Monitor organized into a series of tasks. Each task contains upgrades that provide improvements or additional capabilities to a common area of the prototype system. The various tasks would allow the upgrades to occur as time and funding permits while providing reasonable delivery times in between upgrades. Each task also lists the associated advantages with the proposed upgrades.

Task 1 - *Instrument Packaging*

The first task will be to repackage the current system to make it suitable for a tactical environment. The new instrument package will have the following characteristics:

From the prototype system:

- Pipe section with quick disconnects
- Flow meter and thermocouple
- Flow activated scanning
- Warning lights and alarms
- Custom software for instrument control and inventory tracking
- One in-line probe for fuel monitoring
- Desktop Computer (Fuel Monitoring workstation)
- Real-time transmission of fuel inventory/quality data from the fuel monitor to the desktop via TCP/IP
- Capable of estimating several properties for diesel fuel and kerosene

Modifications and Upgrades:

- "4-man carry" instrument package. Contains all necessary hardware including the instrument, computer, pipe section, *etc.*
- Environment resistant (*i.e.* capable of withstanding extreme weather conditions)
- Reduced instrument weight (by removing the instrument electronics from its current stainless steel enclosure)
- Internal climate control for all components
- NEMA 4/12 panel mount monitor with touch screen interface, sealed keyboard and sealed mouse pad built into the instrument package (replaces the laptop)
- Wireless networking (up to 500 feet)
- External sampling device (cuvette) built into the instrument package

- On-line help with illustrated (video) instructions for setup and use
- Remote instrument diagnostics (by modem)

Advantages:

- Rapid deployment in *any* type of environment
- Hardware setup has been reduced to a minimum
- No need for hardwired network access
- The numerous components required in the original system are now maintained in a single package
- The new packaging prevents the need to handle the fragile fiber-optic cables and other equipment resulting in increased longevity
- Reduced footprint (physical dimensions and weight)
- Instrument problems can be diagnosed from a remotely located site (*e.g.* SwRI)

Task 2 - *Capabilities*

Task 2 will focus on upgrading the instrument's fuel analysis capabilities.

Modifications and Upgrades:

- Investigate the use of mid-infrared instrumentation to replace near-infrared
- Ability to provide property estimates for multiple fuel types (diesel, kerosene, gasoline)
- Ability to discriminate fuel types (diesel, kerosene, gasoline)
- Automated[1] instrument recalibration
- Diagnostics to monitor instrument performance
- Ability to identify potential fuel contamination (*e.g.* water)

[1] Requires some operator assistance

Advantages:

- Mid-infrared spectrometers provide more detailed information about a fuel's chemical composition and fiber-optic cables are not required
- System is more robust
- System becomes deployable at a variety of installations (*e.g.* fuel farms, tank farms, shipyards, airfields, *etc.*)
- System is self-monitoring and thus more reliable

Task 3 - *Handheld Instrument*

Task 3 will be to design a portable device for remote fuel analysis. Technology permitting the device will be handheld. This task will be undertaken once the technology to produce a miniature near-infrared spectrometer has matured to an acceptable level.

Expected Hardware and Capabilities

- Hand transportable instrument package (handheld or briefcase size)
- Rapid analysis of fuel quality (GO/NO GO or full analysis)
- Interchangeable sampling devices (cuvette or probe)
- Possible power sources: rechargeable batteries, vehicle battery, solar power, standard 120 VAC
- Multi-fuel analysis capability (diesel, kerosene, gasoline)
- Ability to discriminate fuel types
- Ability to identify possible contamination (*e.g.* water)
- Use of palmtop computers

Advantages

- No sample preparation

- Easily transported by scout teams in the field
- Can use disposable sampling accessories (cuvettes) so there is no need to carry solvents or compressed air in the field
- Variety of sources for power
- Information stored in computer can be uploaded to main database
- Interchangeable sampling devices give flexibility in the field

Task 4 - *Inventory and Data Presentation*

The fourth task will seek to automate the collection and display of fuel inventory/quality data through additional hardware and software upgrades.

Modifications and Upgrades:

- Handheld and wireless data loggers for entering transactions
- Bar code scanners for data entry
- Wireless (or Wired) flow meters for automated collection of volume data while dispensing or receiving fuel
- Automatic pump shut-offs or flow restriction when fuel specifications are beyond tolerance levels
- Multipoint monitoring (ability to acquire fuel quality data at multiple points simultaneously)
- Upgraded fuel inventory/quality tracking
- Ability to export fuel/inventory quality data
- Ability to print situation reports (local or network printer)
- Ability to track vehicle-specific refueling incidents
- Ability to track inventory for multiple fuel pods and fuel types at a given site

Advantages:

- Access to refueling history for individual vehicles (when, where, by whom, how much, type of fuel, and quality)
- Bar coding automates the entry of vehicle and personnel data into the system
- Added features for plotting/extracting fuel inventory/quality historical data (*i.e.* enhanced database search capability)
- No need to travel between the dispensing site and the monitoring site for data entry
- Automatic pump shutdown prevents contaminated fuel from entering vehicles
- Can monitor feeds from multiple pods and entry and exit points of the fuel distribution system simultaneously
- Wireless devices remove restrictions (*e.g.* distance) imposed by hardwiring

Task 5 - *Integration Upgrades*

Task 5 will seek to globalize the fuel inventory/quality data in an effort to increase total fuel asset visibility.

Modifications and Upgrades:

- Real time transmission of fuel inventory/quality data to secured web site and/or to a server for global distribution
- Renovated Graphical User Interface (GUI)
- Download of fuel inventory/quality data to Personal Data Assistants (PDA)
- Server interfaces (computer, display, and keyboard) located at all fuel

related sites (*e.g.* tank farms, dispensing terminals, pipelines, airfields, shipyards, *etc.*)

- On-line ordering of fuel and spare parts from supply sources and/or units
- Automated scheduling of maintenance/quality checks on vehicles, equipment, and fuel
- Registry of fuel related equipment at each site (*e.g.* petroleum laboratory equipment)
- Each site has a list of parameters identifying its capabilities and inventory (*e.g.* fuel storage capacity, fuel/spare parts on hand, fuel analysis capabilities, *etc.*)

Advantages:

- All fuel related sites are interconnected thereby reducing the communication gap
- Automated re-ordering of fuel and spare parts
- Remote recognition and anticipation of customer fuel status and requirements
- All fuel related equipment is tracked and can be located by a simple database search
- Each site is aware of the capabilities and inventory of every other site
- New GUI is user friendly and displays information in an organized and efficient manner

IX. CONCLUSIONS

Guided by the requirements specified by the United States Marine Corps, the *Remote Near-Infrared Fuel Monitor* was developed to monitor fuel quality and track fuel inventory in real-time. The system was deployed in a remotely located bulk fuel in Twenty-nine Palms, CA

during Hunter-Warrior in 1997. Both contaminated and acceptable fuels were used to test the system with good results. The Remote Fuel Monitor successfully identified contaminated fuel in both the fuel distribution system and in vehicles.

The fuel inventory and quality data that was collected was sent to a remote monitoring station at Camp Pendleton. The remote monitoring station at Camp Pendleton had access to the same vital fuel quality and quantity data as did the bulk fuel farm. As a result, the ability to track fuel inventory and quality was successfully demonstrated. By tracking fuel inventory and quality in real-time, the future requirements of the fuel farm can be anticipated. Using the Remote Near-Infrared Fuel Monitor allows a pro-active, rather than reactive, approach to fuel management.

Based on the experimental data collected during Hunter-Warrior, several modifications to the system have been suggested. These modifications would further ruggedize the system, provide monitoring capability for multiple fuel types, increase inventory tracking capability, and prepare the system for wide-scale use.

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4. Brown, S.D. *Appl. Spectrosc.* **1995**, *49*, 14A-31A.
5. Thomas, E.V. *Anal. Chem.* **1984**, 66, 795A-804A.

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XI. APPENDIX A (Figures)

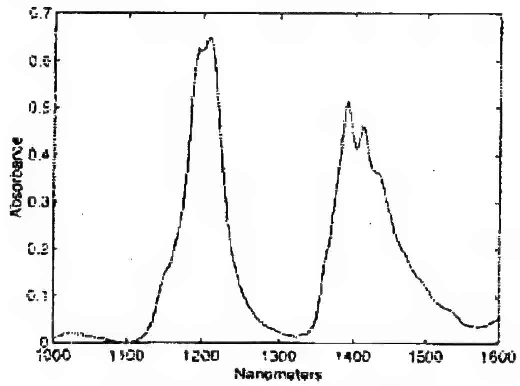

Figure 1. Diesel Fuel Near-Infrared Spectrum

Figure 2. Pipe Section

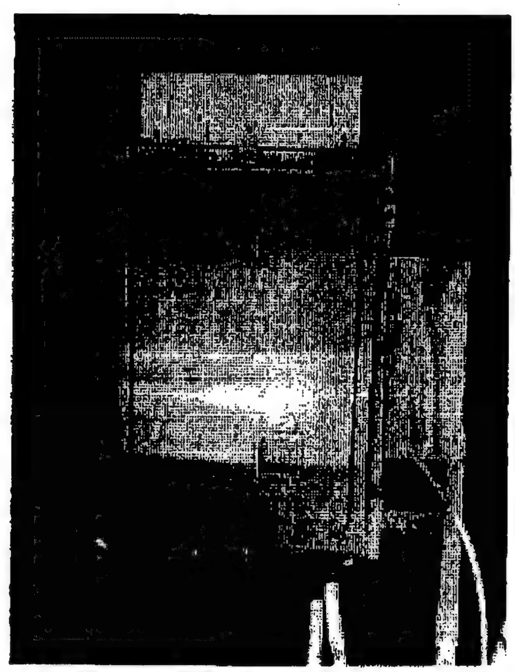

Figure 3. Near-Infrared Spectrometer

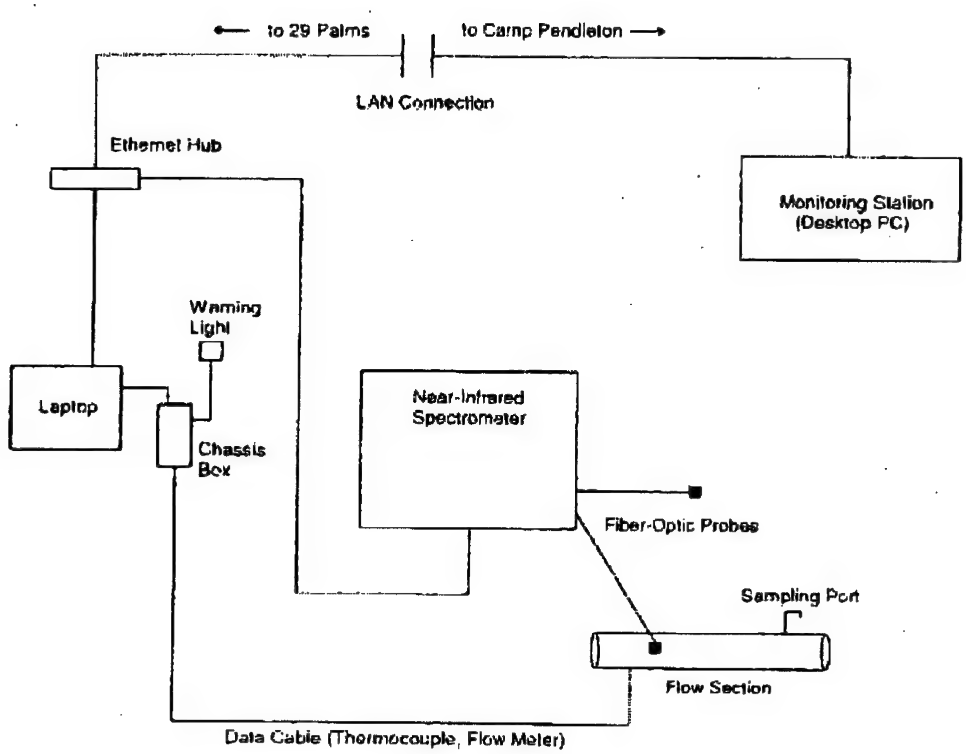

Figure 4. Remote Fuel Monitor (Hunter-Warrior)

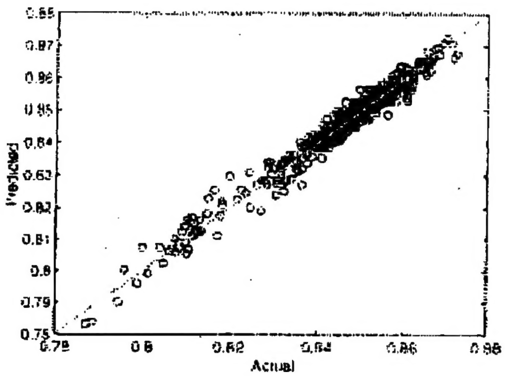

Figure 5. Density

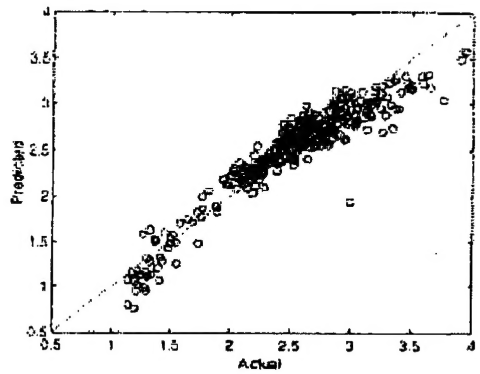

Figure 6. Viscosity

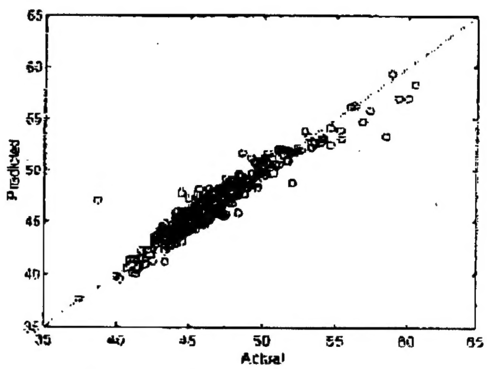

Figure 7. Cetane Index D 4737

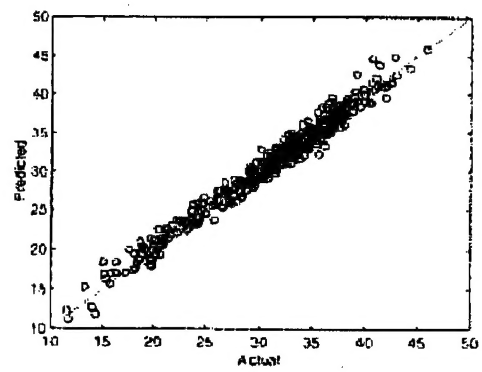

Figure 8. Total Aromatic Content

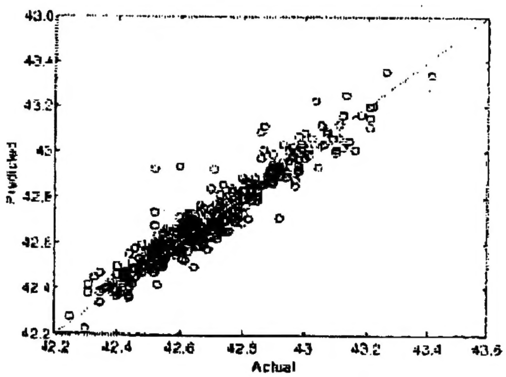

Figure 9. Net Heat of Combustion, MJ/Kg

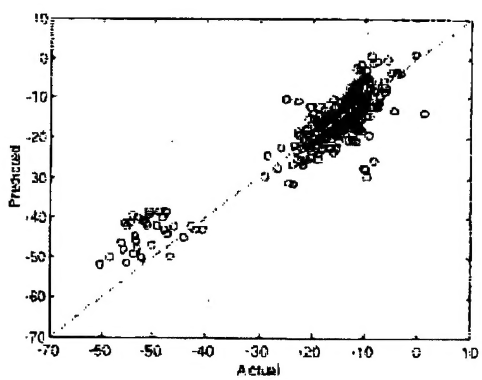

Figure 10. Cloud Point

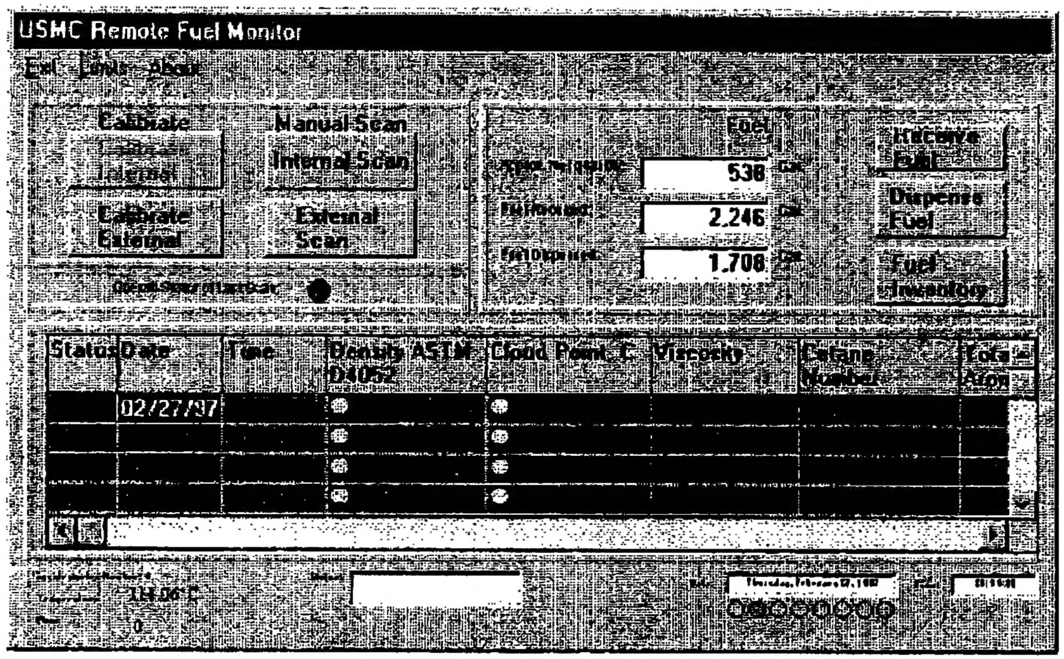

Figure 11. Software for the Ruggedized Laptop

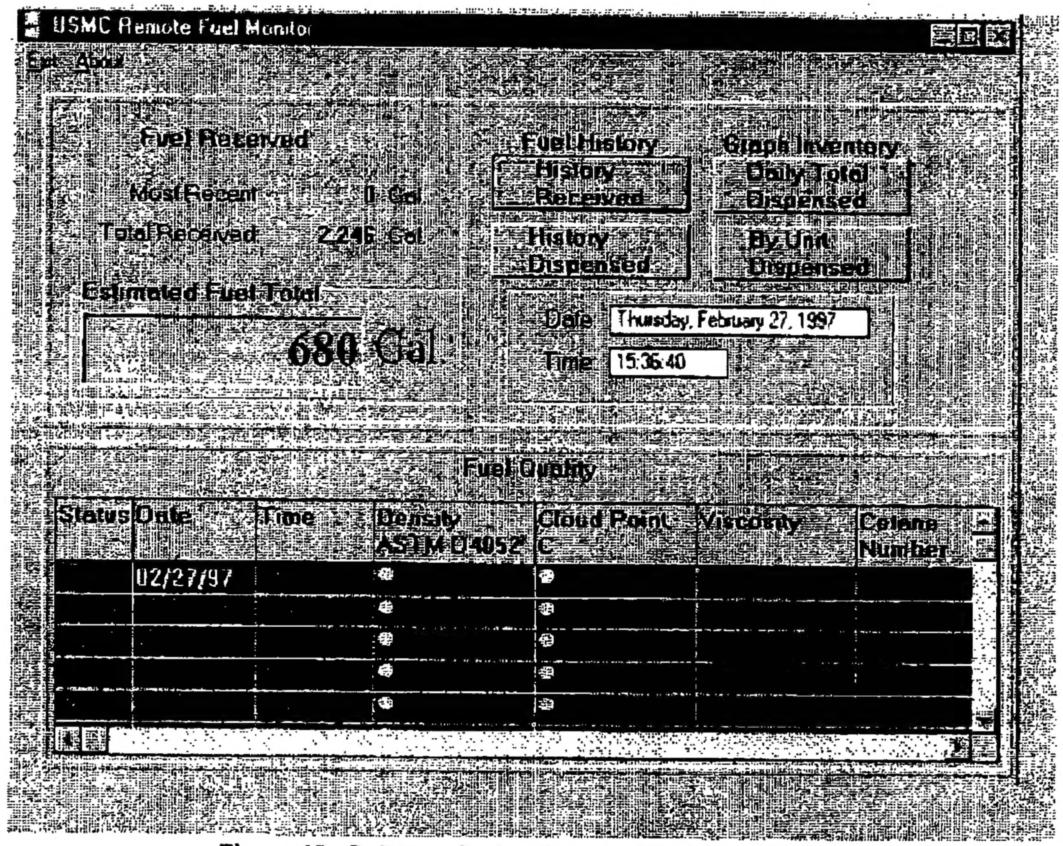

Figure 12. Software for the Remote Monitoring Station

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